Dynamical Evolution of the Scalar Condensate in Heavy Ion Collisions *

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Scalar condensates often appear in quantum field theories when a symmetry is spontaneously broken. Prominent examples include the Higgs condensate and the chiral condensate. The equilibrium behavior of these condensates as a function of temperature and density has been extensively studied in the context of cosmology and heavy ion collisions.

In this paper we have studied the dynamical evolution of the scalar condensate in the $O(N)$ linear sigma model in out-of-equilibrium situations. Our method is based on the following equation of motion

$$\ddot{\sigma}_s - \nabla^2\sigma_s + 2\lambda v^2\sigma_s = -\lambda\Big[3v\sigma_s^2 + \sigma_s^3 + \delta\langle\sigma_f^3\rangle + (v+\sigma_s)(3\delta\langle\sigma_f^2\rangle + \delta\langle\boldsymbol{\pi}^2\rangle)\Big]$$

Dissipation arises because of the response of the correlation functions of the fast modes to the slow modes of the fields. This is treated with standard linear response theory. These response functions should be computed exactly and used in the resulting dissipative, coarse-grained equation of motion. However, such explicit computations are generally not possible to do. Therefore, we identified the physical mechanisms responsible for the dissipation and estimated the corresponding response functions based on them. These mechanisms include the decay of sigma mesons in the condensate, and the knockout of sigma mesons in the condensate due to scattering with thermal sigma mesons and pions. To our knowledge, the latter physical mechanisms have not been studied before.

We then studied the dynamical evolution of the condensate in heavy ion collisions, after the phase transition from quark-gluon plasma to hadrons, and allowing for either one or three dimensional expansion of the hot matter. These showed that thermal equilibrium was reestablished rather rapidly, as shown in the figure, with a time constant of order 2 fm/c. Clearly, much more could be studied along these same lines, including the formation and fate of disoriented chiral condensates (DCC).

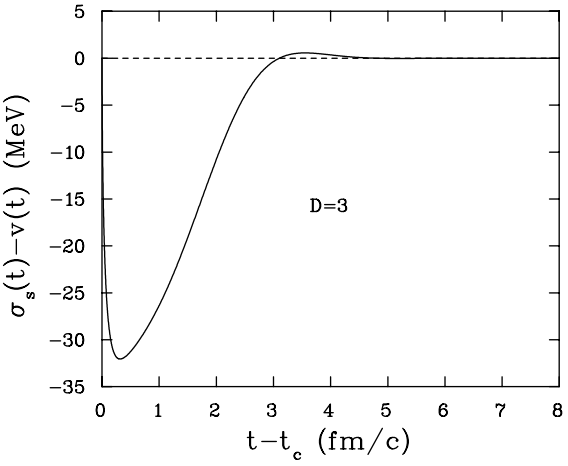

Figure 1: The temporal evolution of the deviation of the scalar condensate from its equilibrium value v in units of MeV for a three dimensional expansion of hot matter produced in a high energy nuclear collision.

The method we used in this paper is very general, and may be applied to other theories, including nuclear matter, QCD, and electroweak theory. Such work is underway.

Footnotes and References

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